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Monitoring and Forecasting the Ionosphere Over Europe: The DIAS Project

Anna Belehaki, Ljiljana Cander, Bruno Zolesi, Juergen Bremer, C. Juren, Iwona Stanislawska, D. Dialetis, and M. Hatzopoulos

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Knowledge of the state of the upper atmosphere, and in particular its ionospheric part, is very important in several applications affected by space weather, especially the communications and navigation systems that rely on radio transmission. To better classify the ionosphere and forecast its disturbances over Europe, a data collection endeavour called the European Digital Upper Atmosphere Server (DIAS) was initiated in 2004 by a consortium formed around several European ionospheric stations that transmit in real-time ionospheric parameters automatically scaled. The DIAS project is a collaborative venture of eight institutions funded by the European Commission eContent Programme. The project seeks to improve access to digital information collected by public European institutes and to expand its use.

The main objective of the DIAS project is to develop a pan-European digital data collection describing the state of the upper atmosphere, based on real-time information and historical data collections provided by most of the operating ionospheric stations in Europe. Various groups of users require data specifying upper atmospheric conditions over Europe for nowcasting and forecasting purposes. The DIAS system is designed to distribute such information.

The successful operation of DIAS is based on the effective use of observational data in operational applications through the development of new added-value ionospheric products and services that best fit the needs of the market. DIAS is a unique European system, and its continuous operation will efficiently support radio propagation services with the most reliable information. DIAS began providing services to users in August 2006.

The Need for Accurate Ionospheric Products

Radio frequency communications and satellite positioning and navigation systems are applications most affected by ionospheric disturbances. Such disturbances can cause drastic and large-scale changes in the usable ranges of high frequency (HF) or below HF bands affecting standard ground-to-ground and submarine communication systems.

The characteristics of an ionospheric propagation channel, whether it is HF or transionospheric frequencies, are highly variable on timescales ranging from a few seconds to the 11-year solar cycle. Even during its quietest periods, the Sun produces electromagnetic radiation and solar wind, both of which can affect a variety of geomagnetic and ionospheric phenomena, which in turn affect radio waves propagating through the ionosphere. Hence day-to-day and hour-to-hour changes in propagation channel characteristics can occur.

Long-term variations, such as that dictated by the solar cycle, are effectively described by long-term prediction programs now in use [*Sojka*, 1989; *Szuszczewicz*, 1990]. However, the scientific knowledge and practical experience gained over the past years have not yet yielded an adequate state-of-the-art capability for short-term forecasting of the very rapid ionospheric changes based on real-time observations. In many practical applications, such short-term variations require a significant amount of radio frequency designers' attention and skills to deal with them.

In principle, these can be handled by well-trained radio operators in their management of channel frequencies. However, such prudent operators are becoming an increasing rarity. Accordingly, users of HF and transionospheric radio systems require assistance with seasonal frequency planning and day-to-day frequency management. Some users apply the real-time channel evaluation (RTCE) technique for the fully adaptive radio system in their management. As the RTCE technique provides information on existing ionospheric conditions, a number of important qualitative predictions can be made with high confidence only by using ionospheric short-term forecasting techniques. These techniques provide vital information on ionospheric conditions that are likely to develop over the next few hours or days.

Users without ionospheric prediction and forecast information may be badly affected when dramatic depressions in foF2 (the maximum ordinary mode radiowave frequency capable of vertical reflection from the F2 ionospheric layer) and in the maximum usable frequency (MUF), caused by polar cap absorption (PCA) or shortwave fadeouts (SWF), produce a total or partial loss of communication. Therefore ionospheric forecasts, specification in real time, and long-term prediction serve an important purpose in frequency planning and management procedures.

The DIAS system has as its primary objectives to cover the needs of the market for reliable information on the current conditions of the ionosphere over Europe and for accurate forecast information over both long-term and short-term timescales. Europe has the advantage, in contrast to other world areas, to have in operation many ionospheric stations with a satisfactory geographic distribution. Nevertheless, even until recently, these stations operated independently, making the full exploitation of the ionospheric observations a very difficult task. DIAS managed for the first time to create a network among most of the European ionospheric stations, to serve radio propagation systems.

Development of the DIAS System and the Distributed Products for Radio Propagation Support

DIAS is a distributed information server [*Belehaki et al.*, 2005] capable of supporting the acquisition, elaboration, evaluation, dissemination, and archiving of ionospheric information. Data are currently obtained from eight European ionospheric stations operated in Athens, Rome, Ebre, Juliusruh, Chilton, Pruhonice, Lycksele, and Warsaw. All stations (mostly digisondes, the digital ionosonde produced by the University of Massachusetts Lowell's Center for Atmospheric Research [*Reinisch*, 1986]) participating in the DIAS network have the capability of automatically scaling and transmitting in near real-time all important parameters characterizing the state of the ionosphere and the propagation of radio waves.

The basic steps of the development of DIAS can be summarized as follows:

1. The DIAS digital server integrates in the same environment and homogenizes all the raw ionospheric data gathered by the eight DIAS ionospheric stations, including ionograms and sounding parameters; the server is designed to integrate in the future any new station that might come online.

2. On the basis of the specification of the potential users' requirements, new competitive added-value products and services for Europe have been defined and designed.

3. State-of-the-art models have been applied to generate the added-value products that are distributed through the system by html, ftp, and e-mail, in static and mobile platforms; these are listed and described in Table 1. An example of one such added-value product, an ionospheric map of the MUF released by the DIAS system, is presented in Figure 1.

4. A network between the DIAS data providers and the users from the research, academic, and industrial sector has been established. Continuous updates on the latest DIAS developments have been communicated through the circulation of monthly e-newsletters. Several meetings have been organized where evaluation discussions on the current version of the DIAS prototype were held, and contacts with all the members have been established through systematic surveys inside the DIAS network.

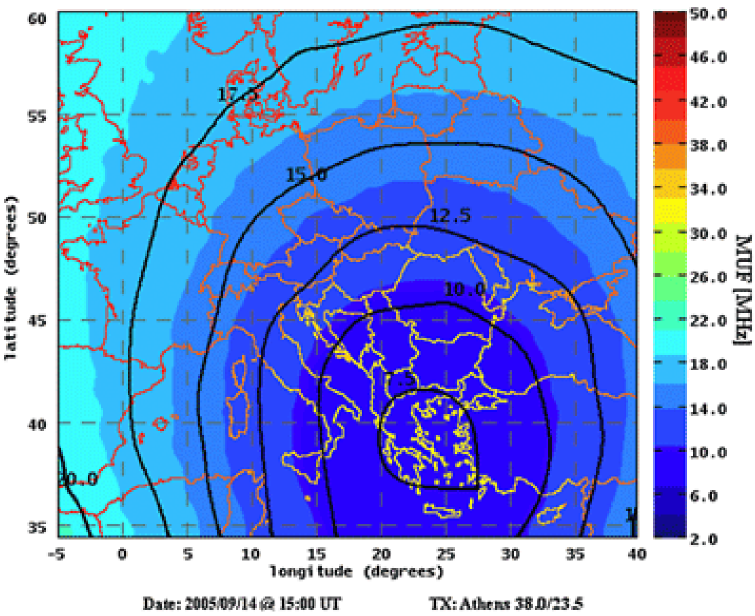

Figure 1. The nowcasting map of the maximum usable frequency for the European region using Athens as the transmitting point.

The DIAS service is already available online (http://dias.space.noa.gr). Users can also visit the Web-demonstrator, a static simulation of the operation of the DIAS system, which is available on the DIAS Web site (http://www.iono.noa.gr/DIAS).

The activities and focused planning surrounding the development and implementation of DIAS also resulted in the identification of the avenues for the commercial exploitation of DIAS products and services, including potential market sectors that might find such products useful. Possible approaches to marketing were determined by the project consortium, and possibilities for future development of DIAS have been considered in order to ensure the viability of the system over the long-term.

Table 1. Value-Added Products

Added-Value Product	Time Resolution	Description
Ionograms	15 min	Real-time and archived ionograms from all DIAS ionosondes in a common layout representation
f-plots	daily plots updated automatically every 15 min	Frequency plots of the standard ionospheric characteristics: the lowest frequency at which echo traces are observed on ionogram (fmin), the ordinary wave critical frequency of the highest stratification in the *F* region (f_oF_2), and the propagation factor M(3000)F_2
Forecasts of f_oF_2	hourly, up to 24 hours ahead	Plots of f_oF_2 forecasted values in each DIAS station location, calculated following the geomagnetically correlated autoregression model (GCAM) [*Muhtarov et al.*, 2002]
Maps of f_oF_2 and M(3000)F_2 long-term forecasts	hourly	Ionospheric maps over the European area of monthly median f_oF_2 for different solar epochs for the long-term prediction of frequency planning services; they are based on the improved simplified ionospheric regional model (SIRM), a model developed specifically for European ionospheric area [*Zolesi et al.*, 1993, 1996, 1999]
Maps of f_oF_2 and M(3000)F_2 now-casting	15 min	Ionospheric maps over the European area of the real-time f_oF_2 and M(3000)F_2 for individual epochs for the nowcasting frequency management; these are based on the real-time updating of the simplified ionospheric regional model (SIRMUP) with autoscaled ionospheric parameters observed by DIAS ionosondes [*Zolesi et al.*, 2004; *Tsagouri et al.*, 2005]
Maps of f_oF_2 forecasting	hourly, up to 24 hours ahead	Ionospheric forecast maps over the European area representative of f_oF_2 conditions up to 24 hours ahead for use in spectrum management; they are based on the SIRMUP technique, using the GCAM forecasted values at the location of DIAS ionosondes for the updating of the grid
Maps of MUF nowcasting and long-term forecasts	hourly	The MUF-SIRM & Lockwood-Webber is the applied method to produce a grid of the basic MUF values for a given transmission point in the European area, and a map of isolines of this parameter; the ionospheric characteristics predicted for a given epoch, namely, f_oF_2 and M(3000)F_2, come from the SIRM and SIRMUP models. A typical Chapman model is then used for f_oE required input values [*Dominici and Zolesi*, 1987; *Davies*, 1990]. Finally, different empirical formulas [*Lockwood*, 1983; *Comité Consultatif International des Radiocommunications*, 1991] are applied to calculate the basic MUF for a transmission between two given points.
Maps of electron density	time: 15 min altitude: 10 km	The applied method, Ne3D, is a three-dimensional model of electron density (*Ne*) in the ionosphere, using real-time calculated electron density profiles from DIAS ionosondes. It gives instantaneous values of *Ne* for a given time, altitude, and for a given location in Europe. The resulting *Ne* at a point (*x,y,h*) is a weighted average of measurements made at different points and a value from the statistical model for this point. The mapping scheme applied uses a specific technique that fits the background model to the set of measurements [*Stanislawska et al.*, 2000; *Stanislawska et al.*, 2001]. To avoid numerical instabilities and ensure a higher accuracy, additional data taken from the NeQuick model [*Leitinger et al.*, 2002] that is used as a background model to add data during the interpolation procedure.
Real-time ionospheric alert index (AI_R)	15 min	To provide a representative picture of the disturbed ionosphere over Europe, the AI_R is derived according to the simple formula: $AI_R(t) = 100^* (f_oF_2(t) - f_oF_2^{med}) / f_oF_2^{med}$ calculated at multiple stations simultaneously. Here $f_oF_2(t)$ is the current observed value at each station and the $f_oF_2^{med}$ is the 30-day running median.
Forecasted ionospheric alert index (AI_F)	hourly	For customers warning purposes, DIAS provides the AI_F index for prediction of ionospheric activity up to 24 hours ahead calculated following the simple formula: $AI_F(t+s) = 100^*(f_oF_2^f(t+s) - f_oF_2^{med(t+s)}) / f_oF_2^{med(t+s)}$ where $f_oF_2^f(t+s)$ is the forecasted value s steps ahead according to the GCAM method and $f_oF_2^{med(t+s)}$ is the 30-day running median for the hour under forecast.

Who will use DIAS?

The demand for reliable products that characterize the state of the ionosphere with high accuracy is great, due not only to the specific needs of the European space industry (European Geostationary Navigation Overlay Service–(EGNOS) and Galileo satellite navigation systems) but also to many applications operated by several market sectors.

DIAS is also able to support the needs of different countries' defense industries, namely the long-term and short-term requirements for ionospheric nowcasts and possible forecasts, as defense has a wide variety of systems (communications, radar, surveillance, intelligence gathering, etc.) that are affected by space weather ionospheric events.

The aviation industry uses HF communication for long-haul air traffic control (ATC) over oceans and in polar regions. During major disturbances, aircraft are not permitted to fly at high latitudes (because they would be out of contact with ATC), but rather are redirected to midlatitude routes, resulting in significant flight delays on routes between Europe and the United States. In disturbed conditions, there will often be poorer communications on midlatitude routes, and the resulting increased air traffic requires greater aircraft separations to maintain safety standards. These factors combine to have significant implications for the airline operating costs, and the use of DIAS products can mitigate these implications.

Civil HF broadcast operators are also concerned with short- to long-term predictions of HF conditions for determining frequency schedules. For this market sector, DIAS can provide extremely important information, especially for civil protection operations during times of natural disasters (such as earthquakes and tornados), where the only reliable means of communicating may be through the HF band.

In addition, space agencies and satellite operators are interested in long-term prediction frequency planning services and thus DIAS could be an important source of information. Finally, for researchers in various fields of geophysics, DIAS could be a useful tool for post-event analysis studies.

In summary, DIAS is the first Europe-wide project aimed at the collection of ionospheric observations from European ionosondes and the development of added-value products for radio propagation services. The major strength of DIAS is that it can easily integrate new sets of observations from other areas around the world, it can be easily updated by newly developed models, and it can follow the latest technological advances. These are the elements that will enable the evolution of DIAS services over the next years and into the future. In the near future, DIAS could posibly expand its services through collaboration with existing ionospheric service providers on other continents–improving the accuracy for the worldwide specification of the ionosphere–and contribute to the development of more accurate products for ionospheric prediction.

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References

Belehaki, A., L. R. Cander, B. Zolesi, J. Bremer, C. Juren, I. Stanislawska, D. Dialetis, and M. Hatzopoulos (2005), DIAS Project: The establishment of a European digital upper atmosphere server, *J. Atmos. Sol. Terr. Phys.*, *67*, 1092–1099.
Comité Consultatif International des Radiocommunications (1991), Atlas of ionospheric characteristics, *Rep. 340-6*, Int. Telecommun. Union, Geneva.
Davies, K. (1990), *Ionospheric Radio, IEE Electromagn. Ser., vol. 31*, 580 pp., Peter Peregrinus, London.
Dominici, P., and B. Zolesi (1987), A model for the normal ionosphere over Rome, *Nuovo Cimento C, Ser. 1*, 10, 191–208.
Leitinger, R., S. Radicella, and B. Nova (2002), Electron density models for assessments studies–New developments, *Acta Geod. Hungarica*, *37* (2-3), 183–193.
Lockwood, M. (1983), A simple M-factor algorithm for improved estimation of the basic maximum usable frequency of radio waves reflected from the ionospheric F region, *Proc. Inst. Electr. Eng*, *130F* , 296–302.
Muhtarov, P., I. Kutiev, and L. R. Cander (2002), Geomagnetically correlated autoregression model for short-term prediction of ionospheric parameters, *Inverse Problems*, *18*, 49–65.
Reinisch, B. W. (1986), New techniques in ground-based ionospheric sounding and studies, *Radio Sci.*, *21* (3), 331–346.
Sojka, J. J. (1989), Global scale physical models of the F region ionosphere, *Rev. Grophys.*, *27*, 371–403.
Stanislawska, I., G. Juchnikowski, R. Hanbaba, H. Rothkaehl, G. Sole, and Z. Zbyszynski (2000), COST251 recommended instantaneous mapping model of ionosphere characteristics: PLES, *Phys. Chem. Earth, Part C*, *25* (4), 291–294.
Stanislawska, I., G. Juchnikowski, and Z. Zbyszynski (2001), Generation of instantaneous maps of ionospheric characteristics, *Radio Sci.*, *36* (5), 1073–1981.
Szuszczewicz, P. (1990), The modelling, measurement and predictability of the global scale ionosphere: Current perspectives and future needs, in *Solar-Terrestrial Predictions: Proceedings of a Workshop at Leura*, *vol. 1* pp. 226–256, Natl. Oceanic and Atmos. Admin., Boulder, Colo.
Tsagouri, I., B. Zolesi, A. Belehaki, and L. R. Cander (2005), Evaluation of the performance of the real-time updated simplified ionospheric regional model for the European area, *J. Atmos. Sol. Terr. Phys.*, *67* (12), 1137–1146.
Zolesi, B., L. R. Cander, and G. de Franceschi (1993), Simplified ionospheric regional model for telecommunication applications, *Radio Sci.*, *28* (4), 603–612.
Zolesi, B., L. R. Cander, and G. de Franceschi (1996), On the potential applicability of the simplified ionospheric regional model to different midlatitude areas, *Radio Sci.*, *31* (3), 547–552.
Zolesi, B., L. R. Cander, and G. de Franceschi (1999), The improved SIRM, a simple ionospheric model for the extended regional European area, paper presented at the URSI XXVI General Assembly, Toronto, Ont., Canada.
Zolesi, B., A. Belehaki, I. Tsagouri, and L. R. Cander (2004), Real-time updating of the simplified ionospheric regional model for operational applications, *Radio Sci.*, *39*, RS2011, doi:10.1029/2003RS002936.

Anna Belehaki is a researcher at the Institute for Space Applications and Remote Sensing, a division of the National Observatory of Athens, Greece, E-mail: belehaki@space.noa.gr

Ljiljana Cander is researcher at the Rutherford Appleton Laboratory in Didcot, U.K.
Bruno Zolesi is a researcher at the National Institute of Geophysics and Volcanology in Rome, Italy.
Juergen Bremer is a researcher at the Leibniz Institute of Atmospheric Physics in Kuhlungsborn, Germany.
Christer Juren is a researcher at the Swedish Institute of Space Physics in Kiruna, Sweden.
Iwona Stanislawska is a researcher at the Space Research Center, a division of the Polish Academy of Sciences, in Warsaw, Poland.
D. Dialetis is a professor at the University of Athens in Greece. M. Hatzopoulos is a professor at the University of Athens in Greece.

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